THE COLLEGE OF AERONAUTICS

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CALIBRATION OF THE FLOW IN THE CHANNEL OF THE WHIRLING ARM

by

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S U M M A R Y

The calibration of the flow in the channel of the Whirling Arm is described and results for pitch, yaw and wind speed are presented. These indicate that the flow is quite acceptable for the type of model tests envisaged.

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List of symbols

d	Dimension shown in Fig. 8
H	Total head
p_o	Side-tube pressures when these are equal
p'	Larger of two side-tube pressures when plane of tubes axes contains wind vector
p_3	Centre-tube pressure
p_s	Static pressure
U	Wind speed
x,y,z	Coordinates shown in Figure 8
θ	Angle of yaw (or pitch)
ρ	Density of air

Suffixes

2	Denotes conditions appropriate to $z = 2$ in.

1. Introduction

The ex-N.P.L. Whirling Arm is currently being developed at the College of Aeronautics as a means of testing the effect of forward speed on the aerodynamic characteristics of ground effect machines. As part of this development programme a study is being made of the flow in the channel (Fig. 1), particularly in the region where the model will be mounted. An initial survey was made by Kumar[1] who indicated the need for more detailed measurements of the various components of flow velocity. This was suggested by obvious discrepancies between the flow velocities recorded on the arm by a pitot-static tube and by pitot-static tubes fixed in the channel. It was thought that this could be due to a pronounced radial velocity in the flow resulting from the gap in the channel through which the arm protrudes (Fig. 1). Consequently Kumar also recommended that this gap should be reduced as far as possible, and this has been done by employing perspex sheet of $^1/_8$ in. thickness.

Since Kumar's work, the extension of the Whirling Arm into the channel and the model support struts have been enclosed in fairings, as shown in Fig. 2. Thus, as a consequence of this modification and the reduction in the gap in the channel, it seems likely that the circumferential and radial swirls in the channel will be reduced.

Before the present flow surveys were undertaken, a study was made of existing yaw/pitch probes with particular regard to the problems associated with the Whirling Arm. From the standpoint of simplicity of operation, the three-tube axial probe devised by Templin[2] appeared to be the most suitable. A sketch of the probe is given in Fig. 3 which shows that it is rotated about its longitudinal axis. During operation this is done until the side-tube pressures are the same; in this case the flow velocity vector is in the plane that is normal to the plane through the tubes and that contains the longitudinal axis of the probe. Then the side tube pressure p_0 and the centre tube pressure p_3 are noted. To define the flow direction completely it only remains to rotate the probe through 90° and to read the larger of the two side tube pressures, p'.

On the basis of this study it was decided to use the Templin probe for the survey of the flow in the channel. Actually, the probe employed differed in one major detail from the original design[2] in that it had an 0.04 in. centre hole instead of 0.02 in. It was thought that this modification would reduce the sensitivity of the probe to scale effect. To reduce asymmetry to a minimum all the flats at the probe leading edge were precision ground.

2. Calibration of the probe

The calibration of the probe was performed in The College of Aeronautics' 8 ft. x 6 ft. wind tunnel, the probe being mounted on a strut from the floor so that the centre hole coincided with the tunnel axis. The probe could be yawed about its nose by rotating the turntable beneath the tunnel floor.

An initial survey indicated that, at the measuring position, the tunnel flow was unyawed but possessed a downward pitch of 0.4°. Therefore, in order to ensure that the flow relative to the probe was unpitched, the probe was set at a nose-up incidence of 0.4°. The probe was then rotated about its longitudinal axis until the plane containing the tubes was vertical. Then, with the probe longitudinal axis initially in the median plane of the tunnel, the tunnel turntable was rotated in a clockwise sense through an angle θ. The results obtained for $(p_3-p_o)/\frac{1}{2}\rho U^2$ (where U is the wind speed) are shown in Fig. 4 plotted against θ. Strictly, of course, θ is not the same as the yaw in the flow relative to the probe axis. However, the difference between the angles is insignificant. Figure 4 shows that there is some scale effect, but it is by no means serious.

In order to establish the flow direction calibration, the probe was rotated through 90° and the yawing procedure was repeated. From this were obtained results for $(p' - p_o)/(p_3 - p_o)$, which are plotted in Figure 5 against θ, and $(p' - p_s)/\frac{1}{2}\rho U^2$, (Fig. 6) where p_s is the static pressure at the measuring station. In both cases, the scale effect will be seen to be not particularly significant.

The procedure used to determine flow direction, $\frac{1}{2}\rho U^2$ and p_s from this information is as follows: having determined the angle of rotation of the probe about its axis needed to equalize the side-tube pressures, one determines $(p' - p_o)/(p_s - p_o)$ and hence θ from Fig. 5. Thus the flow angle is completely defined. With this knowledge of θ, and provided that a rough estimate of wind speed is available, it is possible to obtain $(p_3 - p_o)/\frac{1}{2}\rho U^2$ from Fig. 4, thus giving $\frac{1}{2}\rho U^2$ and U. If this value of the wind speed differs from the estimate it may be used instead to provide a more accurate value. It has been found that this process converges rapidly. Finally, p_s may be obtained from Fig. 6.

3. Flow surveys in the channel

For the majority of the tests the probe was mounted on the arm in the manner shown in Fig. 7. It will be seen that the probe was connected to a plate which was attached to the base of the model support struts. This plate, which was of $^5/_8$ in. thickness and 6 in, chord, was intended to simulate the circumferential swirl that is introduced into the flow by the model to be tested; this is a rectangular wing of 2 ft. chord, 4 ft. span and of Clark Y aerofoil section. The lateral and vertical surveys were made sufficiently far upstream of the plate to ensure that the pitch in the flow induced by the plate was sensibly zero. However, for the longitudinal surveys, the plate was removed to prevent it from influencing the flow measurements. Instead, the probe was attached to a 1 in. x $^1/_4$ in. metal strip which was mounted laterally between two longitudinal struts. The lateral strip was kept a constant 7 in. from the probe head.

In order to ensure that the probe was parallel with the tangent to the path of its holes, it was adjusted until its axis was perpendicular to a wire which ran from the centre of the arm. The incidence of the probe was set at zero by employing a microalignment telescope to align the probe axis with the horizontal. The accuracy of both settings was found to be ± 0.2°.

The pressures registered by the probe were sent via a scanning valve to a pressure transducer whose electrical signals were monitored through slip rings to a pen recorder in the control room. The pressure transducer was mounted inside the fairing surrounding the arm extension in such a manner that its diaphragm contained the centrifugal force vector.

The probe could be rotated about its axis by means of a remotely operated stepping motor which gave angular steps of 0.25°.

Throughout the flow survey tests, the arm was run at 26.8 r.p.m., this being close to the maximum speed available at the present time. However, lower speeds were employed to check whether or not the centrifugal force produced any noticeable outward distortion of the probe and, in consequence, any spurious yaw reading. This series of tests indicated that the yaw in the flow given by the probe was independent of r.p.m., this appearing to support calculations in suggesting that there was no significant probe distortion.

The coordinate system and dimensions relevant to the flow survey tests are shown in Fig. 8. The dimension d shown in this figure could be varied by raising or lowering the channel floor. However, for the surveys to be reported here, d was held constant at 7.5 in., which is considered to be representative for future test configurations.

3.1 Wind speed and total head

3.1.1 Vertical survey

The vertical survey was performed with $x = 10$ in. and $y = 0$, giving a probe speed of 76 ft/sec. The results for the wind speed between the channel floor and $z = 2$ in. are shown in Fig. 9. In this figure it will be seen that the wind speed rises from a value of 59 ft./sec. at $z = 0$ to 63 ft./sec. at $z = -6$ in. This tendency is presumably caused by the ability of the channel floor to extract energy from the swirl. At the channel floor the swirl can be expected to vanish as a consequence of the no-slip condition. Therefore the curve in Fig. 9 has been extrapolated to a value of 76 ft/sec. (the probe speed) at the channel floor.

As z increases, the wind gradient decreases. For $z > -6$ in. the wind gradient is such that the correction to the forces and moments for the wind shear is likely to be small. With the model nearer to the floor the correction will be significant.

As with wind speed, total head was found to increase as the channel floor was approached. This is illustrated in Fig. 10 which shows the vertical distribution of $(H-H_2)/\frac{1}{2}\rho U_2^2$, where H is the total head and suffix 2 denotes conditions appropriate to $z = 2$ in. Evidently, the rise in total head between $z = 2$ in. and $z = -7$ in. is approximately the same as the rise in dynamic pressure, indicating that the flow near the floor is of the boundary layer type.

Wind speed could be measured with an accuracy of ± 0.3 ft/sec.

3.1.2 Lateral survey

The lateral survey was made at $x = 10$ in. and $z = 2$ in., the results obtained for the wind speed being shown in Fig. 11. There it will be seen that the wind speed varies in a linear fashion with y, at least over the range of y examined. Furthermore, it will be seen that the rate of growth is approximately the same as that of the actual speed of the probe.

It was found that total head was independent of y within the range -20 in. $\leq y \leq 20$ in.

3.1.3 Longitudinal survey

This survey was performed with $y = 0$ and $z = -4$ in., and the results obtained for wind speed are illustrated in Fig. 12. This shows that wind speed is virtually independent of x, this also being found to be the case with total head.

3.2 Yaw and pitch

3.2.1 Vertical survey

Results for the vertical survey of pitch and yaw are shown in Figs. 13 and 14. In particular, Fig. 13 shows that, for $z < -2$ in., the pitch in the flow is acceptable. The fact that the pitch increases in the downward sense as z increases for $z > -4$ in. is attributed to the flow interference caused by the horizontal tie-bar fairing (Fig. 8). Subsequent to this survey this fairing, which was of 2 in. thickness and 6 in. chord, was removed. The horizontal tie bar was then given an elliptic cross section of $^5/_8$ in. thickness and 1.5 in. chord. The result was that, at $z = 2$ in., the pitch was reduced from 1.5° downwards to 0.6° downwards.

As indicated in Fig. 14, the yaw in the flow is 'small' and quite acceptable for model tests in the interval -5 in. $< z < 2$ in. In the vicinity of the floor, on the other hand, the yaw is significant and increases in the inward sense, to a value of 2° inwards at $z \simeq 6.5$ in. This would seem to be due to the tendency of three-dimensionalities in the swirl flow to be exaggerated in the boundary layer adjacent to the channel floor.

3.2.2 Lateral survey

Lateral surveys of the pitch, with (a) the horizontal tie-bar fairing in position and (b) this fairing removed and the horizontal tie bar streamlined in the manner mentioned above, are shown in Fig. 15. As noted before, the downward pitch at $z = 0$ is reduced from 1.5° to 0.6° in changing from (a) to (b). In both cases, however, there is a pronounced increase in downward pitch as the model-strut fairings are approached. It is thought that this was due to the pitch caused by the exposed model strut ends. To check this suggestion the outboard model strut fairing was extended downwards 5.5 in., and its base was covered with masking tape, the horizontal tie bar being unfaired as in (b) above. The effect of the modification on the pitch at $y = -10$ in. is evident in Fig. 15, where it will be seen that the downward pitch is reduced from 1.6° to 0.6°. The latter value is in accord with the pitch at $y = 0$, where presumably the effect of the exposed strut ends is comparatively small. Thus it seems likely that, when the model is fitted to the struts and the strut ends are consequently shielded, the pitch will not depart greatly from the value 0.6° downwards between the struts.

Inboard of the inside model strut the downward pitch does not decrease as noticeably with lateral distance away from the strut as it does outboard of the other model strut. The reason for this would seem to be the proximity of the inboard tie bar fairing, to the inboard model strut. It is planned to remove this fairing in the near future and to streamline the inboard tie bar in a similar manner to the horizontal tie bar.

Fig. 16 shows the lateral survey of yaw. It will be noticed that the yaw is most noticeable inboard and outboard of the fairings surrounding the model struts. It is thought that a significant reduction in the magnitude of the yaw in these regions could be obtained by reducing the thickness of these fairings.

3.2.3 Longitudinal survey

Figures 17 and 18 show that the yaw and pitch measured in the longitudinal survey are 'small' and show only slight variation with x.

4. Conclusions

Flow surveys in the channel of the whirling arm have been completed. They indicate that, from the standpoint of the uniformity of the flow, the whirling arm is a practicable device for testing wings and ground effect machines at forward speed. No measurements of turbulence have been made; but, in so far as the results for yaw, pitch and dynamic head obtained were found to be consistent, no large scale unsteadiness in the flow is thought to occur.

The major recommendation of this study is that, where possible, the existing fairings surrounding the struts should either be removed or reduced in size. However, consideration should also be given to the installation of circumferential fences in the boundary layer of the swirl flow in order to reduce the lateral flow there. The analogy here between the present flow and the flow over a swept back wing is clear.

Finally, it should be emphasized that the present surveys have been performed with a particular model configuration in mind. This is designed to have a low drag and, in consequence, a thin wake. Therefore, if it is planned to test a larger, bluffer model, consideration should be given to how the swirl flow might thereby be affected.

References

1.	Kumar, P.E.	The College of Aeronautics Whirling Arm initial development tests. CoA Note Aero. No. 174, 1967.
2.	Bayer, D.W. Walshe, D.E. Garner, H.C.	Pressure probes selected for three-dimensional flow measurement. ARC R and M No. 3037, 1955.

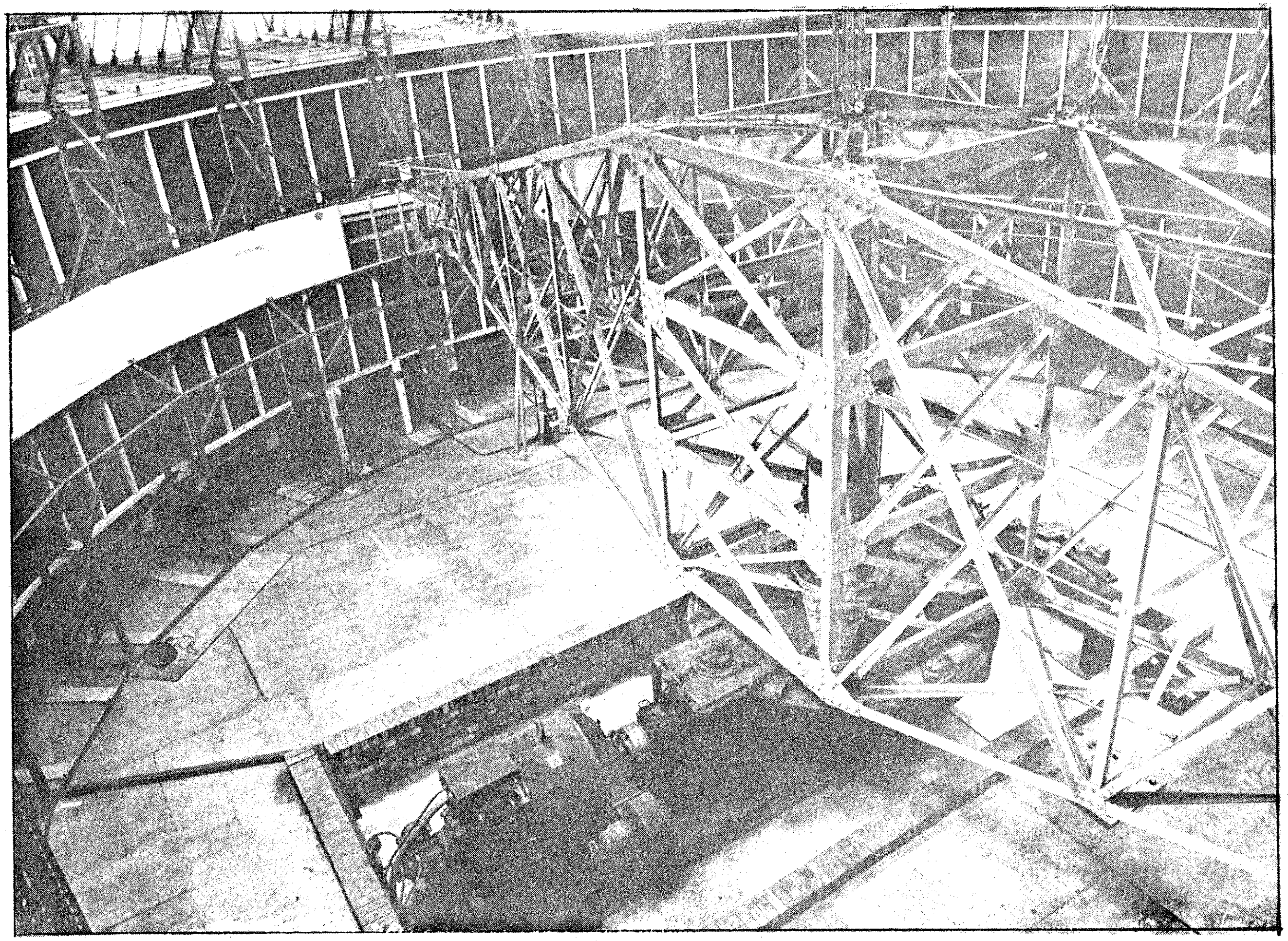

FIG. I. GENERAL VIEW SHOWING WHIRLING ARM CHANNEL

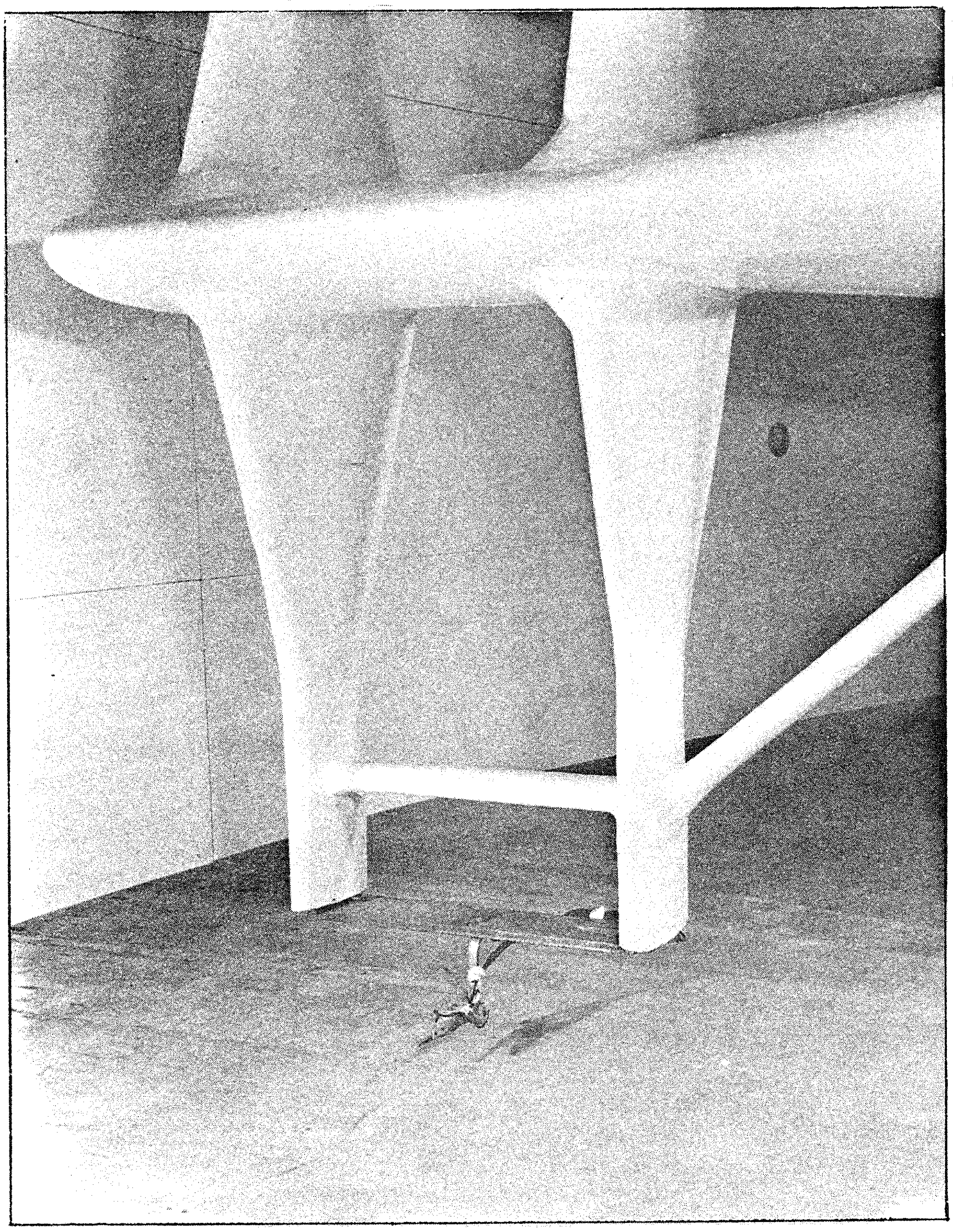

FIG. 2. WHIRLING ARM EXTENSION AND MODEL STRUTS ENCLOSED IN FAIRINGS.

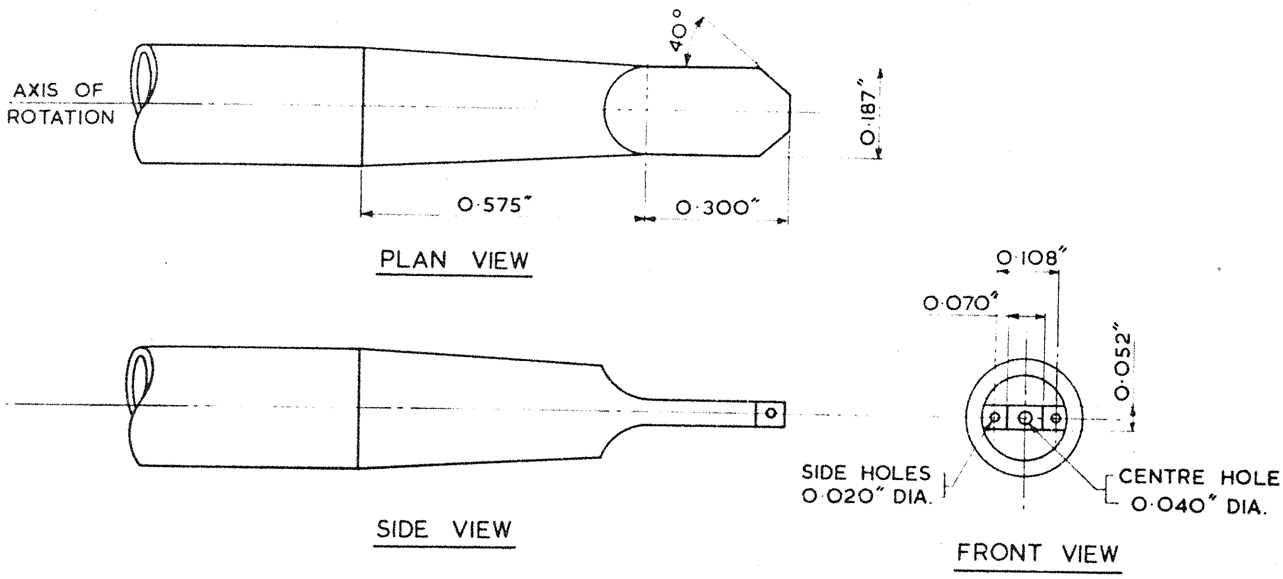

FIG. 3. THE TEMPLIN PROBE.

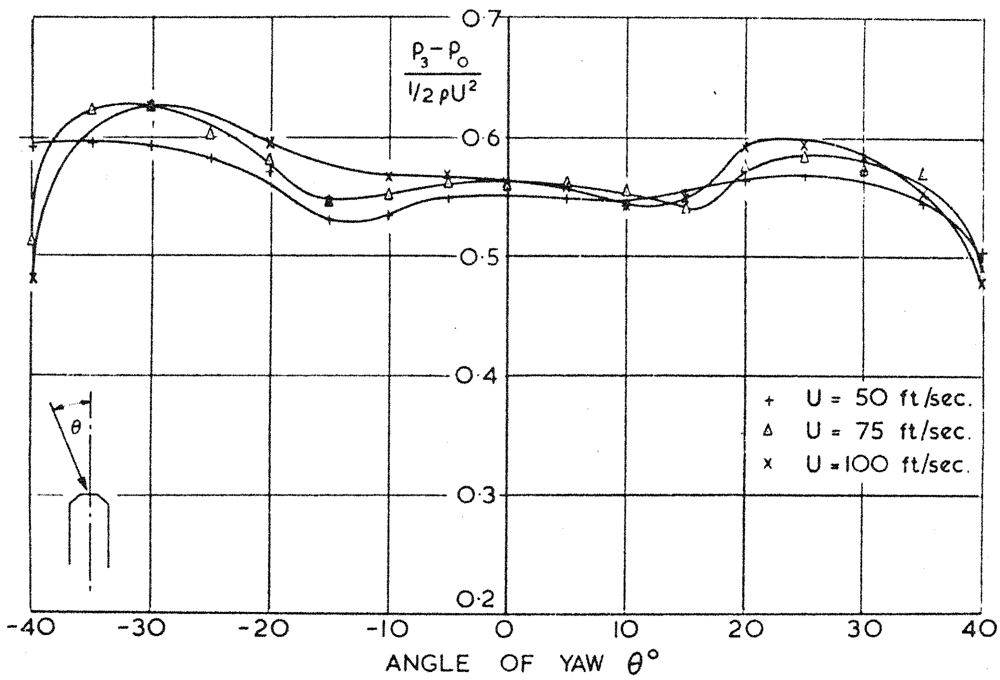

FIG. 4. CALIBRATION OF THE TEMPLIN PROBE ;
(A) DYNAMIC PRESSURE

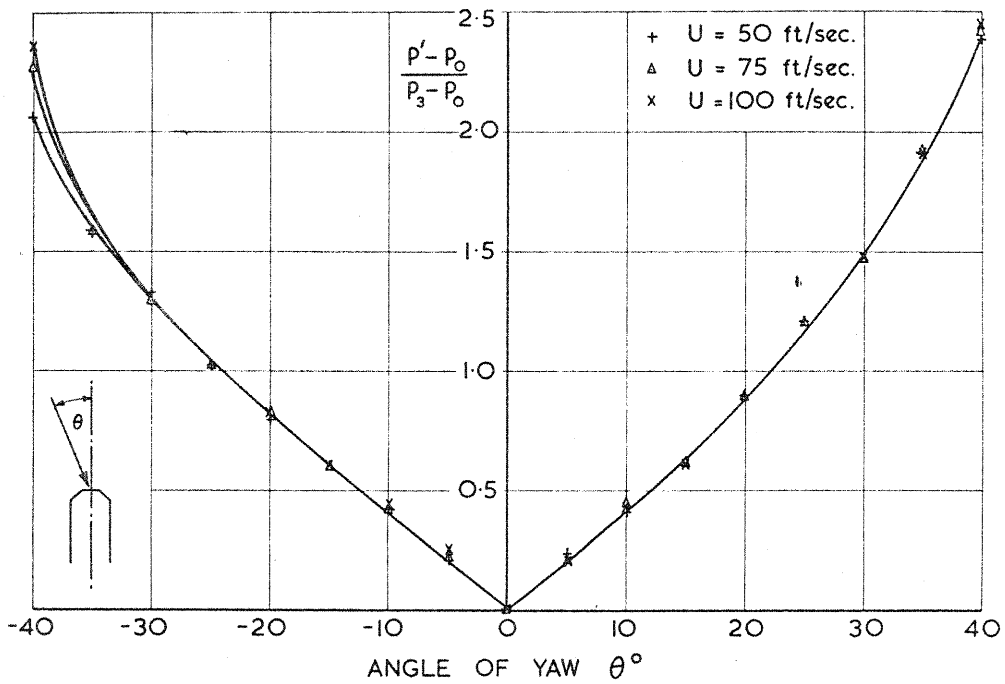

FIG. 5. CALIBRATION OF THE TEMPLIN PROBE ;
(B) FLOW ANGLE

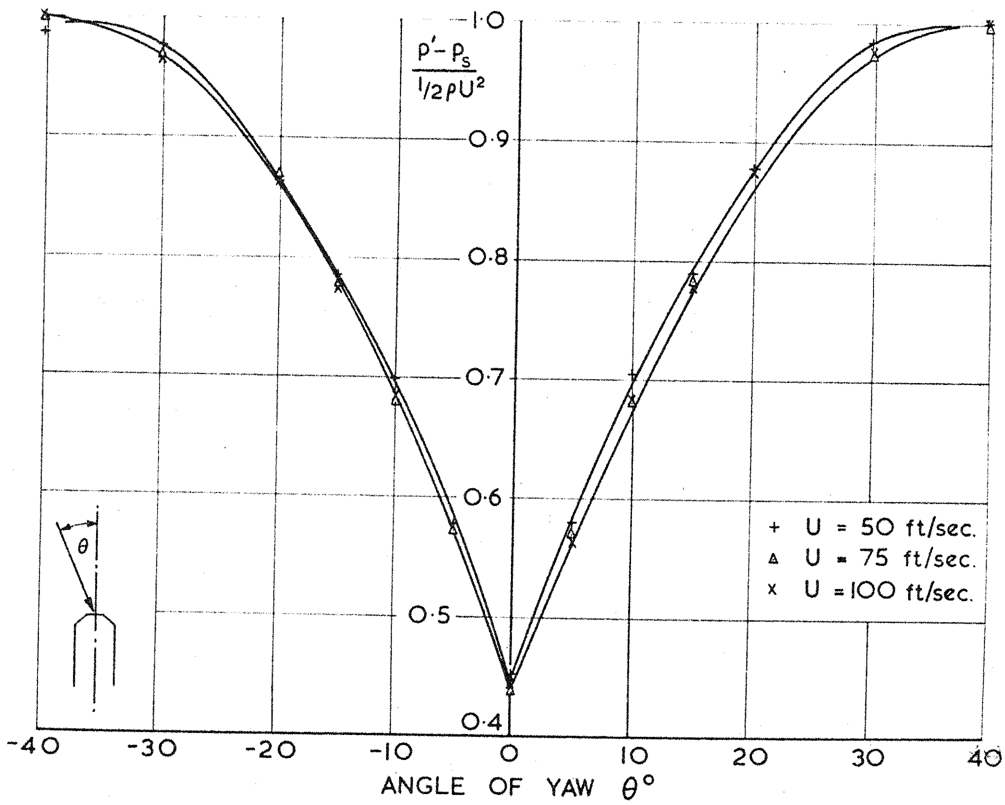

FIG. 6. CALIBRATION OF THE TEMPLIN PROBE ;
(C) STATIC PRESSURE

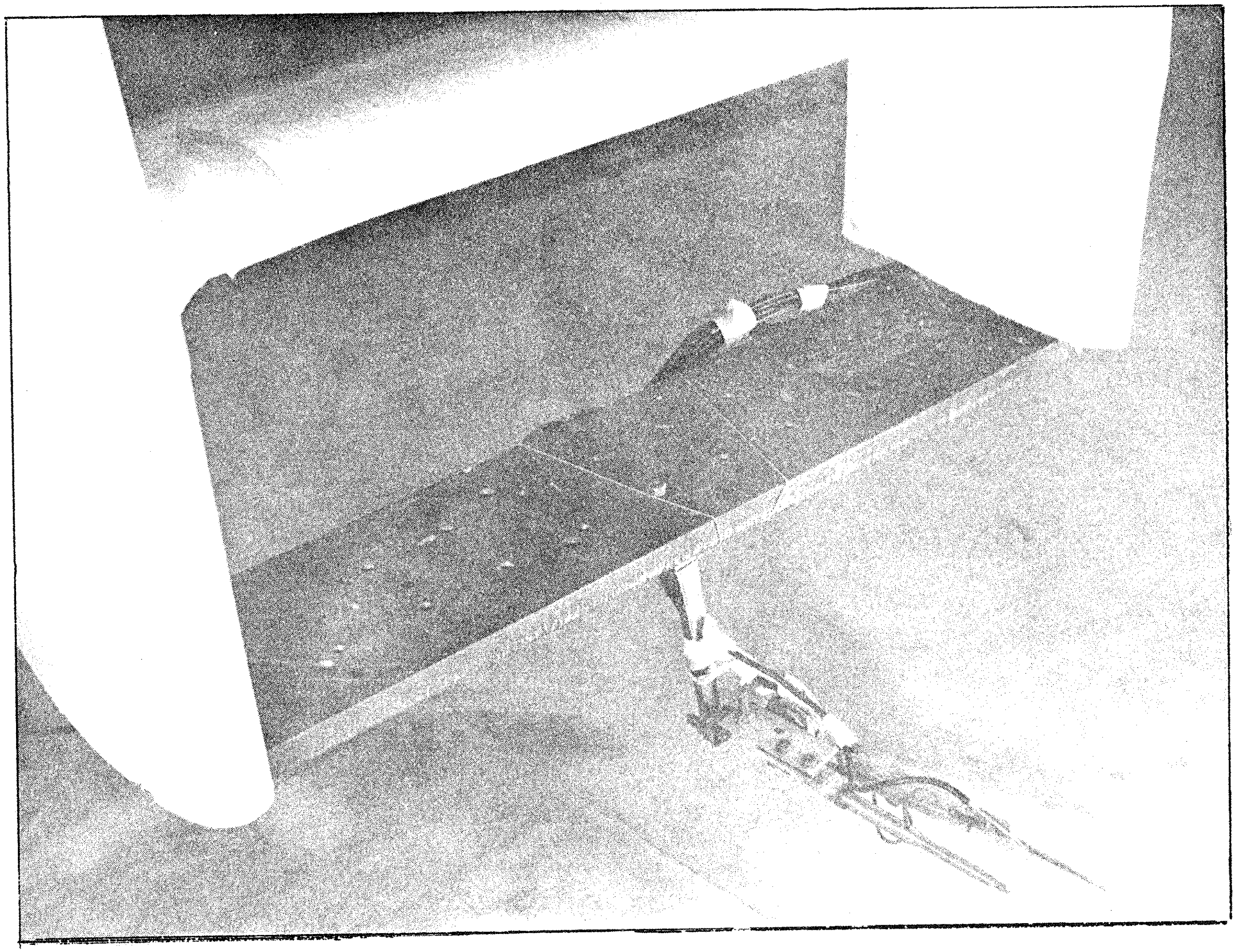

FIG. 7. TYPICAL MOUNTING OF THE TEMPLIN PROBE

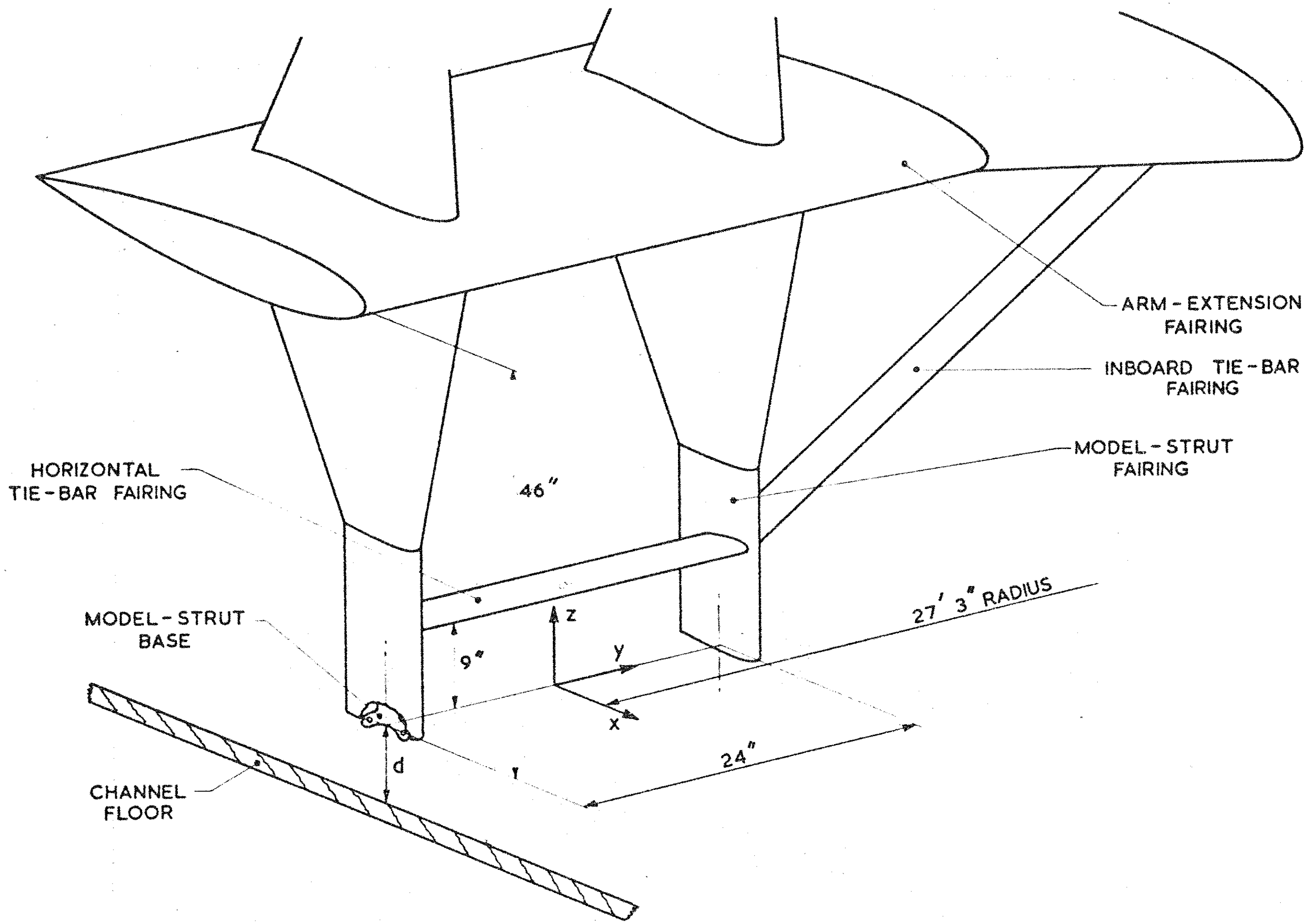

FIG. 8. CO-ORDINATE SYSTEM AND DIMENSIONS RELEVANT TO FLOW SURVEY.

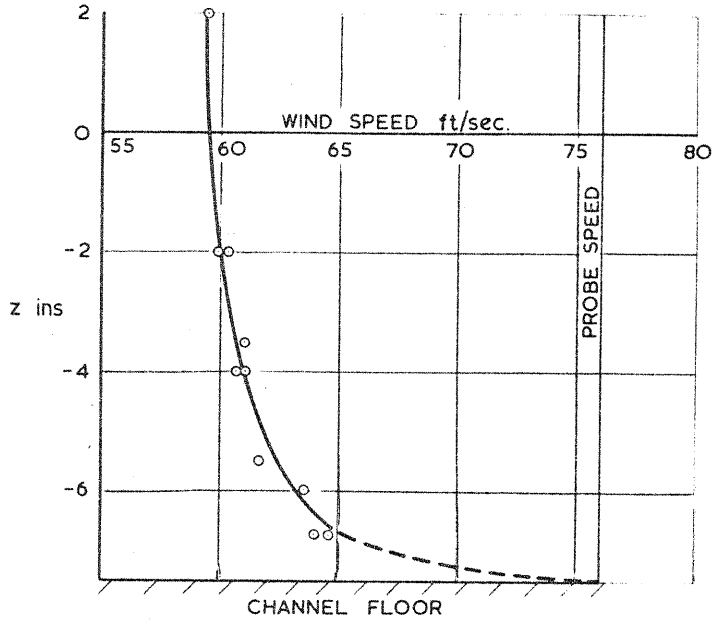

FIG. 9. VERTICAL SURVEY OF WIND SPEED;
$x = +10$ ins , $y = 0$

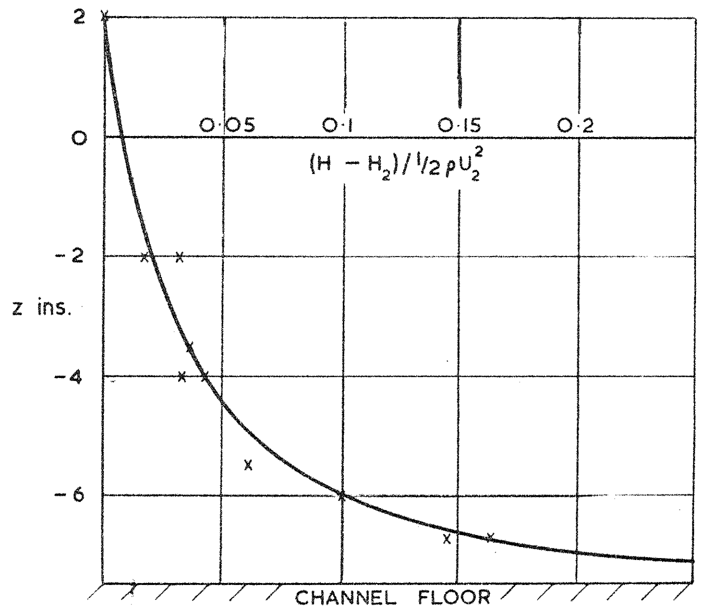

FIG. 10. VERTICAL SURVEY OF TOTAL HEAD;
$x = +10$ ins , $y = 0$

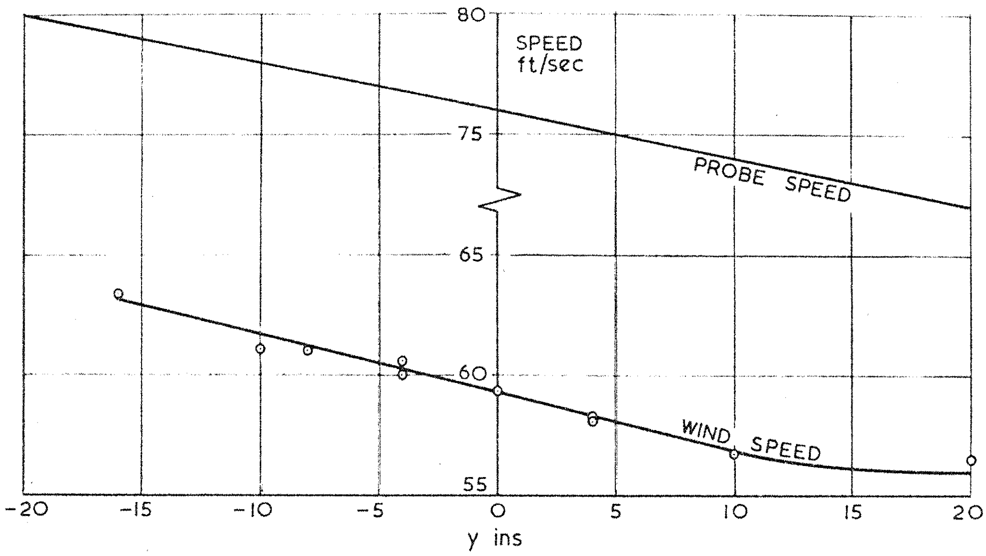

FIG. 11. LATERAL SURVEY OF WIND SPEED;
x = + 10 ins, z = + 2 ins

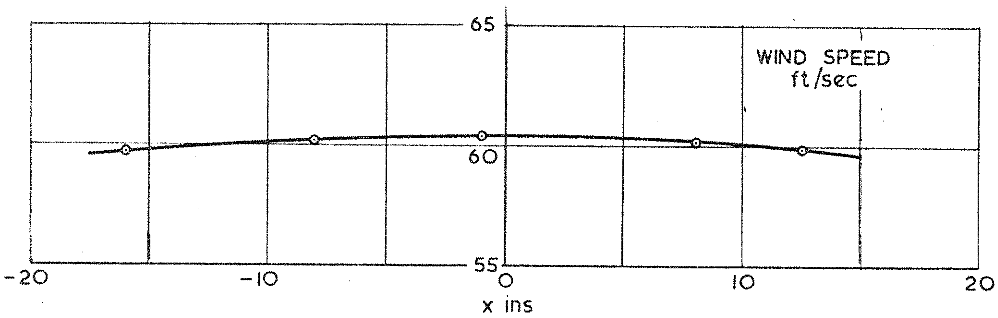

FIG. 12. LONGITUDINAL SURVEY OF WIND SPEED;
y = 0, z = - 4 ins.

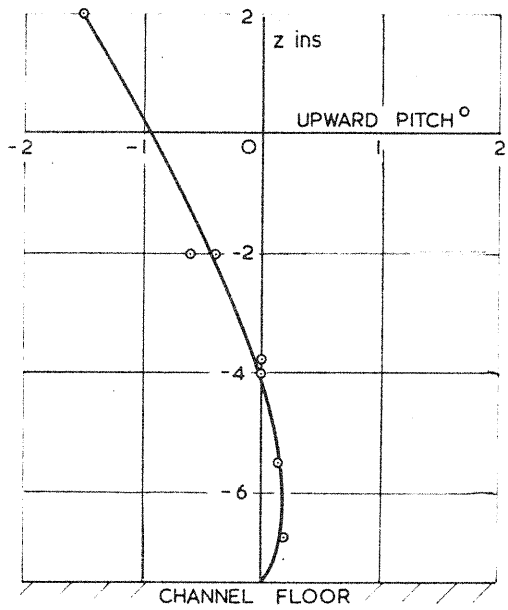

FIG. 13. VERTICAL SURVEY OF FLOW
PITCH; x = 10 ins, y = 0.

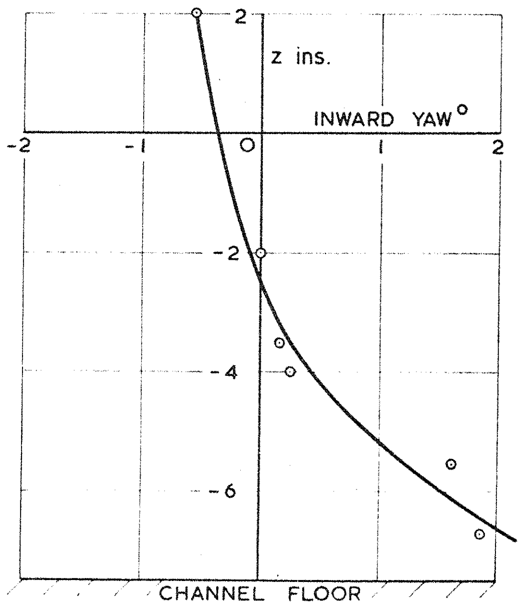

FIG. 14. VERTICAL SURVEY OF FLOW
YAW; x = 10 ins, y = 0.

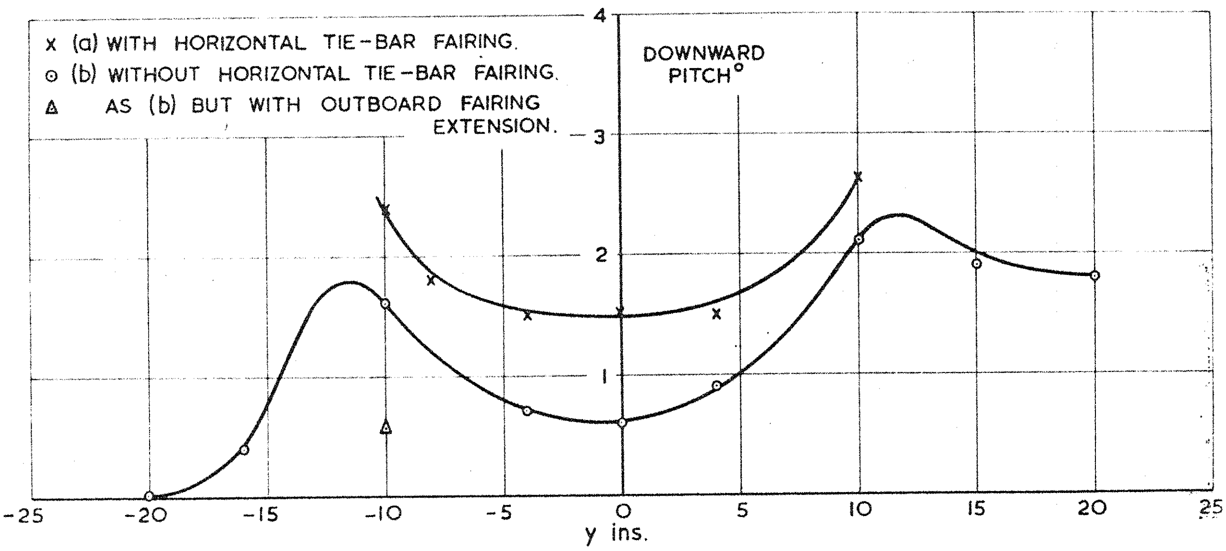

FIG. 15. LATERAL SURVEYS OF FLOW PITCH, $x = 10$ ins, $z = 2$ ins.

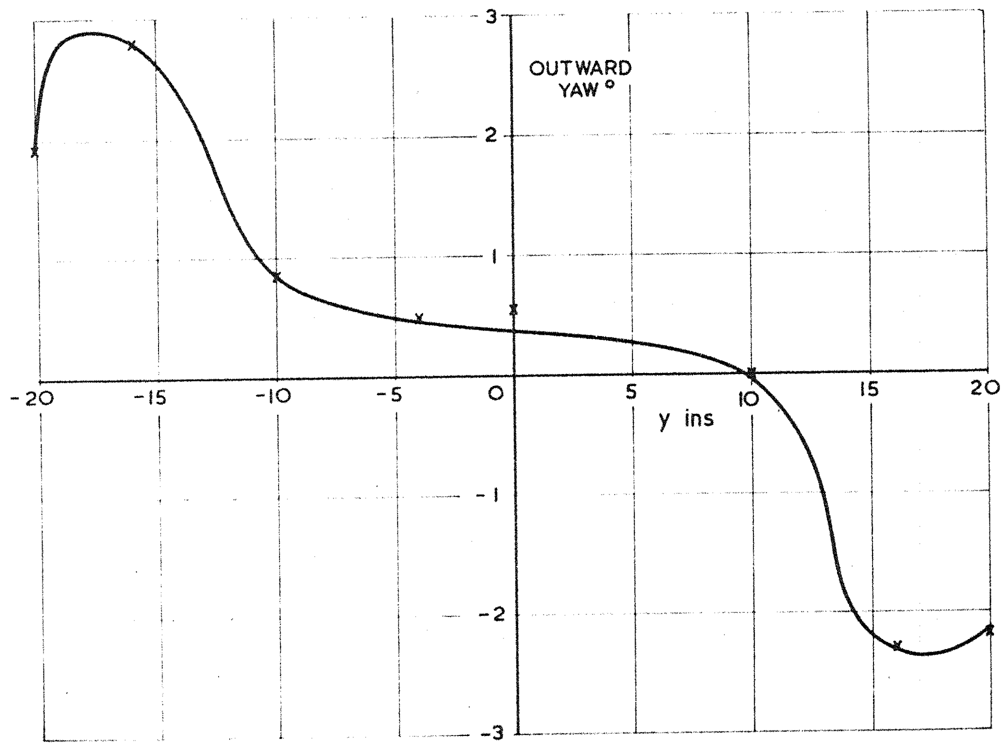

FIG. 16. LATERAL SURVEY OF FLOW YAW; $x = 10$ ins, $z = 2$ ins.

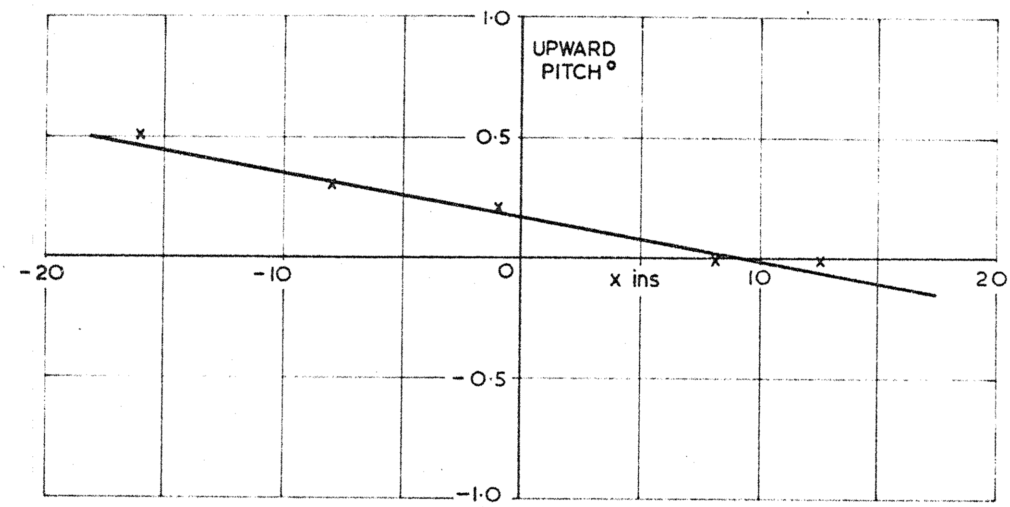

FIG. 17. LONGITUDINAL SURVEY OF FLOW PITCH;
$y = 0, \quad z = -4$ ins.

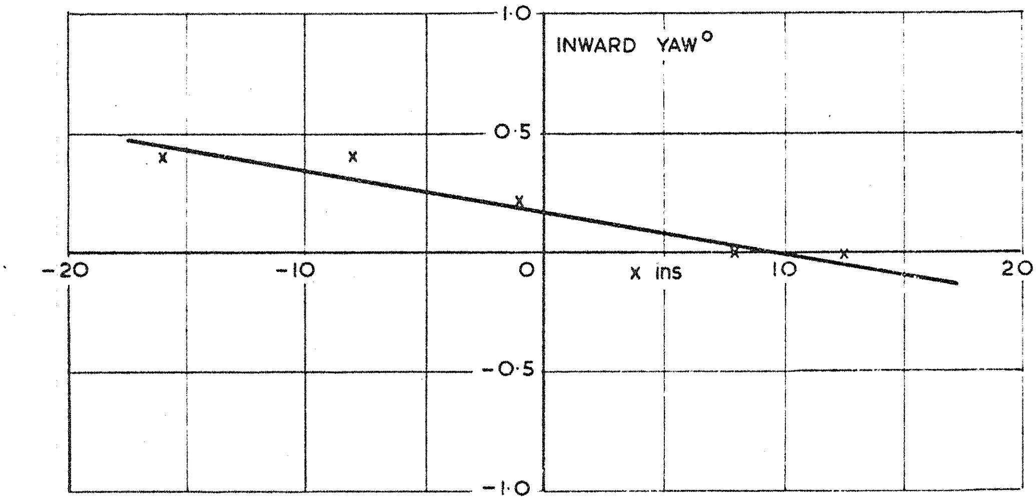

FIG. 18. LONGITUDINAL SURVEY OF FLOW YAW;
$y = 0, \quad z = -4$ ins.